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TRANSPORTATION ENGINEERING – I

DEPARTMENT OF CIVIL ENGINEERING

FACULTY OF ENGINEERING & TECHNOLOGY

TRANSPORTATION ENGINEERING – I (Highway Engineering) UNIT-2 LECTURE - 1

Topics to be covered:

- Vertical Curves and Types
- Summit Curves
- Design of Summit Curves
- Valley Curves
- Design of Valley Curves
- Problems on the Topics Discussed

PREPARED BY:

SHASHIKANT SRIVASTAVA

ASSISTANT PROFESSOR DEPARTMENT

OF CIVIL ENGINEERING

FACULTY OF ENGINEERING & TECHNOLOGY

RAMA UNIVERSITY UTTAR PRADESH, KANPUR (INDIA)

VERTICAL CURVES AND TYPES :

- A vertical curve gives a progress between two slanted streets, permitting a vehicle to arrange the height rate change at a continuous rate instead of a sharp cut.
- The plan of the bend is reliant on the proposed structure speed for the street, just as different variables including drainage, slant, adequate pace of progress, and contact.
- These bends are explanatory and are appointed positioning dependent on a level hub.
- The vertical alignment of highway generally defined as the presence of heights and depths in vertical axis with respect to horizontal axis of alignment.
- These heights and depths in roads may be in the form of gradients (straight lines in a vertical plane) or vertical curves.
- Roadway vertical alignments consist of crest and sag curves with straight grades connecting them.
- The vertical profile is typically displayed as a graph with elevation on the vertical axis, and horizontal alignment distance on the horizontal axis.
- Geometric design of the proposed profile is governed by safety, vehicle operations, drainage and construction issues.
- The vertical curves are generally classified into 2 categories namely:

(1) Summit Curve or Crest Curve

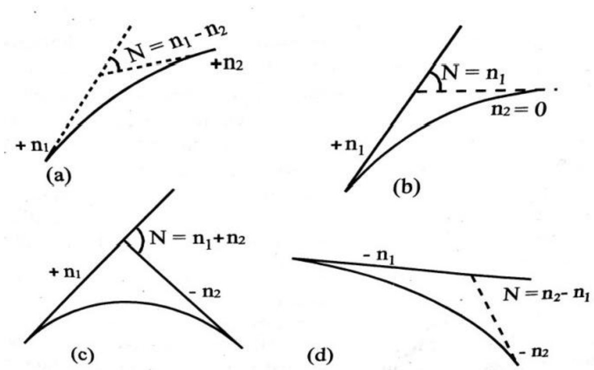
(2) Valley Curve or Sag Curve

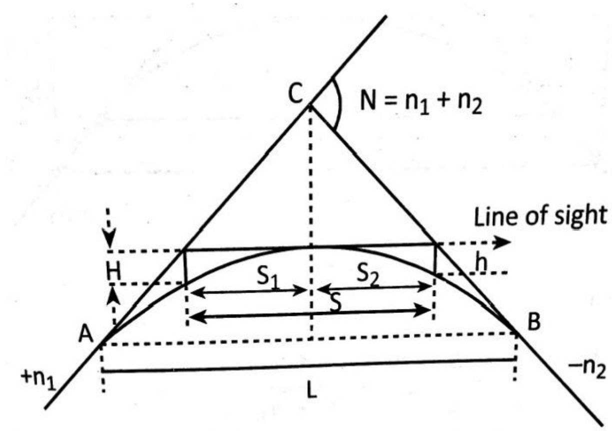
SUMMIT CURVE OR CREST CURVE : Summit curves are vertical curves with gradient upwards. They are formed when two gradients meet as in any of the following four ways:

1. When a positive gradient meets another positive gradient.
2. When positive gradient meets a flat gradient.
3. When an ascending gradient meets a descending gradient.
4. When a descending gradient meets another descending gradient.

VERTICAL CURVES AND TYPES :

TYPES OF SUMMIT CURVE : Many curve forms can be used with satisfactory results; the common practice has been to use parabolic curves in summit curves. This is primarily because of the ease with it can be laid out as well as allowing a comfortable transition from one gradient to another. Although a circular curve offers equal sight distance at every point on the curve, for very small deviation angles a circular curve and parabolic curves are almost congruent. Furthermore, the uses of parabolic curves were found to give excellent riding comfort.





DESIGN CONSIDERATION :

- In determining the type and length of the vertical curve, the design considerations are comfort and security of the driver, and the appearance of the profile alignment.
- Among these, sight distance requirements for the safety is most important on summit curves.
- The stopping sight distance or absolute minimum sight distance should be provided on these curves and where overtaking is not prohibited, overtaking sight distance or intermediate sight distance should be provided as far as possible.
- When a fast moving vehicle travels along a summit curve, there is less discomfort to the passengers.
- This is because the centrifugal force will be acting upwards while the vehicle negotiates a summit curve which is against the gravity and hence a part of the tyre pressure is relieved.

DESIGN CONSIDERATION FOR LENGTH OF THE SUMMIT CURVE :

➢If the curve is provided with adequate sight distance, the length would be sufficient to ease the shock due to change in gradient. Circular summit curves are identical since the radius remains same throughout and hence the sight distance.

- From this point of view, transition curves are not desirable since it has varying radius and so the sight distance will also vary.

➢The deviation angle provided on summit curves for highways are very large, and so the a simple parabola is almost congruent to a circular arc, between the same tangent points.

- Parabolic curves is easy for computation and also it had been found out that it provides good riding comfort to the drivers.
- It is also easy for field implementation.
- Due to all these reasons, a simple parabolic curve is preferred as summit curve.

LENGTH OF THE SUMMIT CURVE : The important design aspect of the summit curve is the determination of the length of the curve which is parabolic. The length of the curve is guided by the sight distance consideration as: a driver should be able to stop his vehicle safely if there is an obstruction on the other side of the road. Equation of the parabola is given by $y = ax^2$, where $a = \frac{N}{2L}$, where N is the deviation angle and **l** is the length of the curve. In deriving the length of the curve, two situations can arise depending on the uphill and downhill gradients when the length of the curve is greater than the sight distance and the length of the curve is greater than the sight distance.

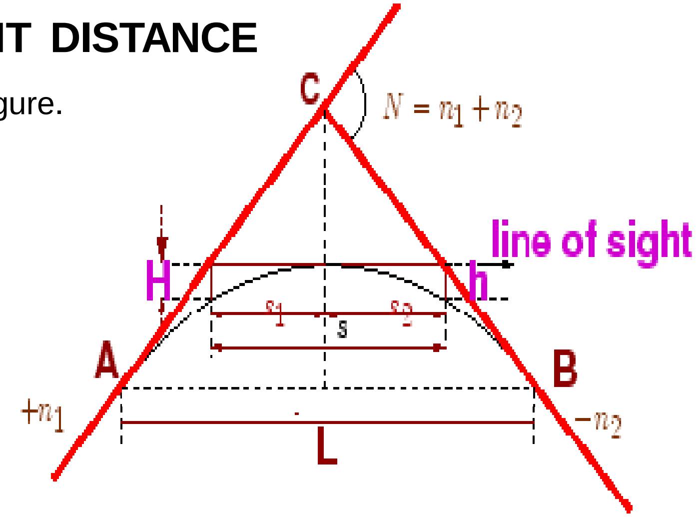
Let **L** is the length of the summit curve, **S** is the SSD/ISD/OSD, **N** is the deviation angle, h_1 driver's eye height (1.2 m), and h_2 the height of the obstruction, then the length of the summit curve can be derived for two cases as:

CASE A: Length of summit curve greater than sight distance **(L > S)**

CASE B : Length of summit curve less than sight distance **(L > S)**

LENGTH OF THE SUMMIT CURVE :

CASE A. LENGTH OF SUMMIT CURVE GREATER THAN SIGHT DISTANCE



The situation when the sight distance is less than the length of the curve is shown in figure.

$y = ax^2$, $a = N / 2L$,

$h_1 = aS_1^2$, $h_2 = aS_2^2$

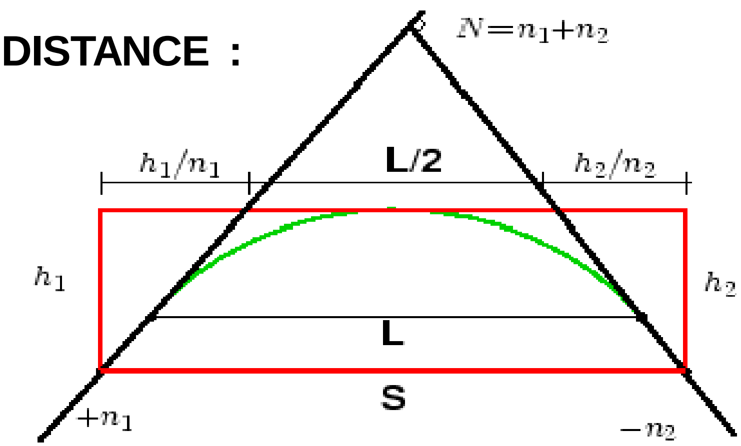
$S_1 = \sqrt{h_1/a}$, $S_2 = \sqrt{h_2/a}$

$$S_1 + S_2 = \sqrt{\frac{h_1}{a}} + \sqrt{\frac{h_2}{a}}$$

$$S^2 = \left(\frac{1}{\sqrt{a}}\right)^2 \left(\sqrt{h_1} + \sqrt{h_2}\right)^2 = \frac{2L}{N}\left(\sqrt{h_1} + \sqrt{h_2}\right)^2$$

$$L = \frac{NS^2}{2\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}$$

CASE B. LENGTH OF SUMMIT CURVE LESS THAN SIGHT DISTANCE :



From the basic geometry, one can write:

$$S = \frac{L}{2} + \frac{h_1}{n_1} + \frac{h_2}{n_2} = \frac{L}{2} + \frac{h_1}{n_1} + \frac{h_2}{N - n_2}$$

$$L = 2S - \frac{2\left(\sqrt{h_2} + \sqrt{h_1}\right)^2}{N}$$

$$L = 2S - \frac{\left(\sqrt{2h_1} + \sqrt{2h_2}\right)^2}{N}$$

When stopping sight distance is considered, height of driver's eye above the road surface (h_1) is taken as 1.2 m. and height of object above the pavement surface (h_2) is taken as 0.15 m. If overtaking sight distance is considered, then the value of driver's eye height (h_1) and height of the obstruction (h_2) are taken equal as 1.2 m.

VALLEY CURVES AND TYPES :

- The curve in a vertical alignment which is produced when two different gradients meet is known as vertical curves.
- It is provided to secure safety, safety, appearance and visibility.
- In the case of valley curves, the use of cubic parabola is preferred as it closely approximates the ideal transition requirements.
- Valley curve or sag curves are vertical curves with convexity downwards.
- When two grades meet at the valley (sag) and the curve will have convexity downwards, the curve is simply referred as the valley (sag) curve.

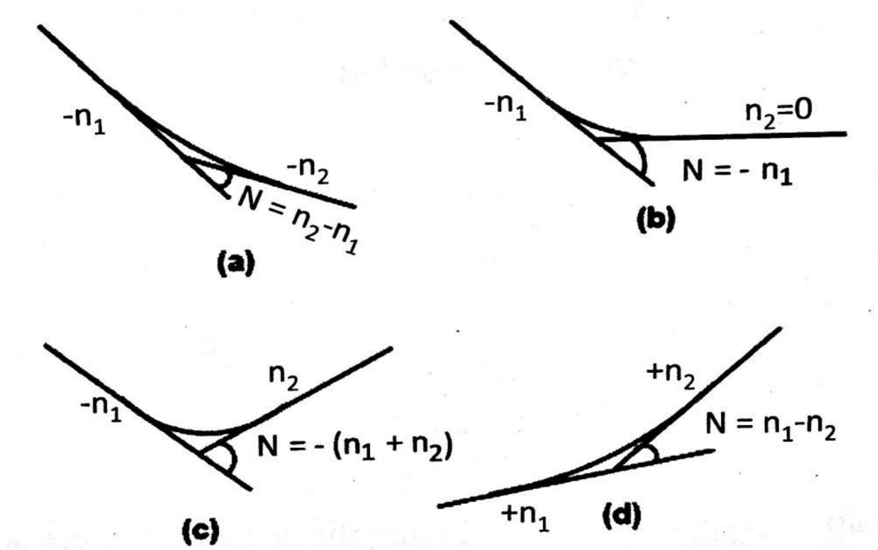
They are formed when two gradients meet as any of the following four ways:

1) When a negative gradient meets another mild negative gradient

2) When a negative gradient meets a level zero gradient

3 When a negative gradient meets with a positive gradient

4) When a positive gradient meets another steeper positive gradient



VALLEY CURVES AND TYPES :

As compared to the design of summit curve, valley curve requires more consideration.

During day time the visibility in valley curves is not hindered but during night time the only source of visibility becomes headlight.

In the absence of street lights and in valley curves, the centrifugal force generated by the vehicle moving along a valley curve acts downwards along with the weight of the vehicle and this adds to the stress induced in the spring of the vehicle which causes jerking of the vehicle and discomfort to the passengers.

Thus, the most important things to consider during valley curve design are:

a) Impact and jerking free movement of vehicles at design speed

b)Availability of stopping sight distance under headlight of vehicles during night driving

The best shape for a valley curve is transition curve.

Some prefer to use the circular curve or quadratic parabola or combined circular spiral curve but mostly cubic parabola is generally preferred in vertical valley curves.

Valley curve is made fully translational by providing two similar transition curves of equal length.

It is set by cubic parabola $y = bx^3$ where $b = 2N / 3L^2$.

The length of the valley transition curve is designed to the following two criteria:

DESIGNING OF LENGTH OF VALLEY CURVES :

COMFORT CRITERIA :

This is used in design to provide impact-free movement of vehicles at design speed. In this criterion, the allowable rate of change of centrifugal acceleration (c) is limited to a comfortable level of $0.6 m/s^3$.

The rate of change of centrifugal acceleration is given by,

Or, $c = [(v^2 / R) – 0] / t = (v^2 / R) / (Ls / v)$

Then, $Ls = v^3 / (c*R)$

For a cubic parabola, the value of R is given by,

$R = Ls / N$

Substituting value of R we get,

$Ls = (N*v^3) / (c*Ls)$

Or, $Ls^2 = (N*v^3) / c$

Therefore, $Ls = \sqrt{[(N*v^3) / c]}$

The total length of the valley curve is given by,

$L = 2*Ls = 2* \sqrt{[(N*v^3) / c]}$

Where, L is the total length of the valley curve, N is the deviation angle, v is the design speed and c is the rate of change of centrifugal acceleration which may be taken as $0.6 m/s^3$.

Applying value of $c = 0.6 m/s^3$ we get,

$Ls = 0.19 \sqrt{(N*v^3)}$

$L = 0.38 \sqrt{(N*v^3)}$

DESIGNING OF LENGTH OF VALLEY CURVES :

SAFETY CRITERIA :

Sight distance is highly reduced during headlight driving conditions during night time. The sight distance within which the head lights can illuminate is known as head light distance and it should be equal to the stopping sight distance. There is no problem of overtaking operation at night because of low traffic and the fact that other vehicles with headlights can be seen from a considerable distance. This design provides adequate stopping sight distance for vehicles under headlight at night time at any part of the curve. It may be determined from two conditions:

Length of the valley curve is greater than the stopping sight distance

At the lowest point of the valley curve, the sight distance will be minimum because at the bottom of the curve where there is minimum radius which is a property of the transition curve.

From the geometry of the figure, we have,

Or, $h_1 + s \tan \alpha = as^2$

Where, $a = N / (2L)$

Then, $h_1 + s \tan \alpha = Ns^2 / (2L)$

Therefore,

$L = (Ns^2) / (2h_1 + 2s \tan \alpha)$

Where N is the deviation angle, s is the sight distance, h1 is the height of the headlight beam from the road surface and α is the head beam inclination in degrees.

Taking, $h_1 = 0.75$m [NRS] and α≈1 ÌŠ we get,

$L = (Ns^2) / (1.5 + 0.035s)$

DESIGNING OF LENGTH OF VALLEY CURVES :

Length of the valley curve is less than the stopping sight distance

In this case, the minimum sight distance will be at the beginning of the curve because the headlight beam at the beginning of the curve will just hit outside of the curve. But at the bottom of the curve, the headlight beam will reach far beyond the end point of the curve. Hence the length of the curve is determined to assume that the vehicle is at the beginning of the curve. From the geometry of the figure, we have,

Or, $h1 + s \tan \alpha = (s - L/2) * N$

Therefore,

$L = 2*s - (2h1 + 2s \tan \alpha) / N$

Where N is the deviation angle, s is the sight distance, h1 is the height of the headlight beam from the road surface and α is the head beam inclination in degrees.

Taking, $h1 = 0.75m$ [NRS] and $\alpha \approx 1$ ÌŠ we get,

$L = 2*s - (1.5 + 0.035s) / N$

The expression above is approximate but it is satisfactory in practice because the gradients are very small. During design, both cases need to be calculated because we will not know prior which case has to be adopted. After calculation, we adopt the greater length among the two during design.

According to the specification of NRS 2045, the criteria to be adopted are that the stopping sight distance shall be equal to the headlight sight distance and the centripetal acceleration is limited to 0.3 m/s2.

PROBLEMS ON DESIGNING OF LENGTH OF SUMMIT AND VALLEY CURVES :

1. A vertical summit curve is formed by N1 = +3.0% and N2 = -5.0%. Design the length of the summit curve for V=80 kmph. (Hint: SSD=128m). [Ans: 298m]
2. N1 = +1 in 100, N2 = -1 in 120. Design summit curve for V=80kmph, OSD=470m. [Ans: L=417m]
3. N1 =+1/50 and N2 = -1/80, SSD=180m, OSD=640m. Due to site constraints, **L** is limited to 500m. Calculate the length of summit curve to meet SSD, ISD and OSD. Discuss results. [Ans: L for SSD=240m, okay, L for OSD=1387m, > 500m not ok, L for ISD=439m ok.]
4. A valley curve is formed by descending gradient N1 = 1 in 25 and ascending gradient N2= 1 in 30. Design the length of the valley curve for =80kmph. (Hint: c=0.6 m/cm^3 , SSD=127.3m) [Ans: L=max(73.1,199.5)]

PROBLEMS ON THE TOPICS DISCUSSED

1. The design of horizontal and vertical alignments, super elevation, gradient is worst affected by _____________

a) Length of vehicle

b) Width of vehicle

c) Speed of vehicle

d) Height of vehicle

2. The most raised portion of the pavement is called _____________

a) Super elevation

b) Camber

c) Crown

d) Kerb

3. The extra width of pavement is provided on _____________

a) Horizontal curve

b) Width of pavement

c) Length of pavement

d) Super elevation

4. Transition curve is introduced in _____________

a) Horizontal curve

b) Circular curve

c) Between horizontal curve and circular curve

d) Vertical curve

PROBLEMS ON THE TOPICS DISCUSSED

5. The most important factor that is required for road geometrics is ____________
   a) SSD
   b) OSD
   c) ISD
   d) Speed of vehicle
6. A part of pavement raised with respect to one side keeping the other side constant is called ____________
   a) Footpath
   b) Kerb
   c) Super elevation
   d) Camber
7. In India, the type of traffic assumed to design pavements is?
   a) Low traffic
   b) Heavy traffic
   c) Mixed traffic flow
   d) Very low traffic
8. The braking efficiency mainly depends on ____________
   a) Sight distance
   b) PIEV theory
   c) Friction
   d) Length of the curve
9. The unevenness index for a good pavement surface of high speed should be ____________
   a) 1500mm/km
   b) 2500mm/km
   c) 3500mm/km
   d) 4500mm/km
10. The camber required depends on ____________
    a) Type of pavement
    b) Rainfall
    c) Type of pavement and rainfall
    d) Rainfall characteristics

PROBLEMS ON THE TOPICS DISCUSSED

11. The camber is not provided in which of the following shape?
    a) Straight
    b) Parabolic
    c) Combination of straight and parabolic
    d) Circular
12. The equation of parabolic camber is given by ____________
    a) Y=x/a
    b) $Y=x^2/a$
    c) $Y=x^3/a$
    d) $Y=ax^2$
13. A median is also called as ____________
    a) Traffic separator
    b) Traffic junction
    c) Traffic check post
    d) Traffic flow
14. The minimum shoulder width recommended by IRC is ____________
    a) 1.0m
    b) 1.5m
    c) 2.0m
    d) 2.5m
15. A road running parallel to highway for some selected areas with grade separator are called ____________
    a) Footage road
    b) Urban road
    c) Frontage road
    d) Parallel highway
16. The boundary till which building activities are prohibited is called ____________
    a) Right of way
    b) Boundary line
    c) Building line
    d) Control line

PROBLEMS ON THE TOPICS DISCUSSED

17. The length visible to driver at any instance of time is called ____________

    a) Sight distance

    b) Visibility limit

    c) Head light distance

    d) Overtaking sight distance

18. The stopping sight distance does not depend on ____________

    a) Break reaction time

    b) Speed of vehicle

    c) Length of vehicle

    d) Friction

19. The desirable relationship between OSD and length of overtaking zone is ____________

    a) Length of overtaking zone = OSD

    b) Length of overtaking zone = 2 OSD

    c) Length of overtaking zone = 3 OSD

    d) Length of overtaking zone = 5 OSD

20. The reaction time of a driver assumed in OSD is ____________

    a) 1 sec

    b) 2 sec

    c) 2.5sec

    d) 3 sec

"Thank you"

Have Any Query ?

Ask us @ shashikant.fet@ramauniversity.ac.in or shashikantchitransh3@gmail.com